

## **APPENDIX A**

### **Wheel/Axle/Wheel Resistance Recommendations**



## CONCLUSIONS AND RECOMMENDATIONS FOR WHEEL TO WHEEL RESISTANCE OPERATING PERFORMANCE

Consideration was given to the maximum wheel-to-wheel resistance allowable in a new specification to be written to cover wheelsets of rail vehicles. In the past, there have been no requirements for this, as solid axle wheelsets always have exhibited such a low resistance that it was insignificant in the total shunting picture.

However, with the advent of split or stub axle wheelsets, it is necessary to specify a maximum allowable wheel-to-wheel resistance to assure that the wheelset will properly shunt the track. This obviously has to be less than the 0.06 ohms (60 miliohms) used as the standard for track circuit shunt sensitivity setup in North America.

Exactly how much less is open to question. It is virtually impossible to approach the problem on any other than empirical basis because the total shunting resistance of a wheelset includes the wheel-to-rail resistance which has proven to be highly variable. However, a number of resistance measurements have been made on conventional solid axle wheelsets and the values of wheel-to-rail shunting resistance under favorable conditions is generally known. Thus it is possible to develop a maximum wheel-to-wheel resistance figure that has some meaning in fact and precedents in experience if not in absolute quantitative terms.

In discussion, it was agreed that any resistance value which would likely satisfy the mechanical fraternity would be too high for the signal fraternity to accept. Using slip rings and brushes or metallic contact through the bearings would almost certainly result in a wheel-to-wheel resistance large with respect to the 0.060 ohm total shunt standard now used. Consequently, efforts were directed toward establishing a maximum allowable resistance value which would not adversely affect shunting using the current 0.060 ohm standard.

In the measurements made by in the course of the Track Circuit Parameter (TCP) working group activities, maximum wheel-to-wheel resistance for a solid axle wheelset were in the tens of microohms. Thus they were very small with respect to the 0.060 ohm shunting standard. Also, experience of the working group members was that wheel-to-rail resistance was well under 0.060 ohms under normal clean wheel-clean rail conditions. Values under 10 miliohms (total for both wheels) are typical. Thus, the .060 track circuit adjustment standard affords a degree of a safety factor for increased wheel-rail contact resistance due to dirt, rust or other semiconductive films.

It was the conclusion of the working group that this safety factor should not be significantly eroded by introducing a wheel-to-wheel resistance which was large with respect to the normal wheel-to-rail resistance. Also, it should be relatively insignificant with respect to the 0.060 ohm track circuit adjustment standard.

After considering a range of values from 1 to 50 miliohms, the group decided on a maximum of 6 miliohms (0.006 ohms). This is well in excess of the values measured for conventional solid axle wheelsets, so does not impose an unrealistic value that would be difficult to meet using current technology. This also is 10% of the track circuit adjustment standard so would be fairly insignificant in determining performance of a present track circuit/wheelset combination.

## **APPENDIX B**

### **OGI Report**



**INVESTIGATION OF SURFACE FILMS ON RAILS AND WHEELS**  
for the  
Association of American Railroads

by  
Milt Scholl and Paul Clayton  
Oregon Graduate Institute for Science and Technology

**RAILS AND WHEELS EXAMINED:**

Following received and examined in laboratory.

**Buford Site A.** Rail from TTC - D.C. resistance measurements made, sectioned, examined in SEM and by FTIR, also took scrapings for examination in TEM. Used to try methods of sample collection and for examination methods/techniques. (all done)

**Sterling Site H.** Rail from TTC, from revenue service. D.C. resistance measurements made, took scrapings for examination in TEM and in SEM. Used to try methods of sample collection and for examination methods/techniques. (all done)

Field rail samples, Burlington Northern revenue line, Washington. Took scrapings from rail when possible in areas identified by RCL meter and probe (Scott Gage, AAR). These examined in SEM and TEM.

From crossing east of Bonneville dam between two curves at Cooks Crossing. Samples BN1, BN1-A, and BN4-A. Samples poor due to high winds in area blowing away scrapings.

From crossing near Washougal on main line, tangent track. Samples WA5-1, WA5-2, WA5-3. Good samples, rail had very thick films. Field side had very thick, loose films. On gage and running surface there was very adherent films. Sample WA5-1 from the region of the thick film, while WA5-3 was from the center of the rail head.

Wheel samples from Burlington Northern Wheel Shop, Vancouver, WA. Samples taken from areas identified by RCL meter and probe (Scott Gage, AAR). Examination in SEM (done) and TEM.

**UP Car Wheel**, UP218228, covered hopper car. Scrapings from wheels set already removed from car.

**BN Car wheel**, BN624136, box car. Scrapings from wheel set already removed from car.

Wheel and brake block samples from AAR, Chicago. Examination in SEM (done) and TEM.

**AAR Brake Wheel**, section from brake block rig test. Wheel re-machined flat for test. Scrapings taken from surface. This was wheel no. 65129, run under a continuous braking load of 60 HP at a speed of 40 mph.

**AAR Brake Block, Surface**, scrapings taken from brake block used on the Brake Wheel. Samples taken from the surface contact region.

**AAR Brake Block, Bulk**, scrapings taken from brake block used on the Brake Wheel. Samples from the un-affected bulk material.

**AAR Car Wheel**, section from a wheel which had been in revenue service. Scrapings taken from surface.

Field wheel samples from North Platte, NE, Union Pacific wheel shop.

**NORX 2488 L3**, auto transport car, scrapings from wheel already removed from car, axle 3, left wheel.

**NORX 2488 R3**, auto transport car, scrapings from wheel already removed from car, axle 3, right wheel.

**UP 79760**, unknown car type, scrapings from wheel already removed from car.

**Wheel 57990**, and **Wheel 47166**, Wheelset from unknown car, scrapings from wheel already removed from car.

Field rail samples from Gothenburg, NE test site, areas identified by RCL meter and probe (Scott Gage, AAR)

**North Rail, Goth.**, north rail of north trackset. Westbound traffic, many coal empties.

**South Rail, Goth.**, south rail of south trackset. Eastbound traffic, many full coal trains.

Field wheel samples from Lincoln, NE, Burlington Northern rip shop in main yard. Primarily rolling stock repair with considerable traffic through shop of cars in immediate use.

**KCLX 91054 L1**, from aluminum 200t coal car, axle 1, left wheel. Car in for brake system work.

**KCLX 91054 R1**, from aluminum 200t coal car, axle 1, right wheel. Car in for brake system work.

**BN 447453 L1**, from covered hopper grain car, axle 1, left wheel. Car in for coupler replacement.

**BN 447453 R1**, from covered hopper grain car, axle 1, right wheel. Car in for coupler replacement.

Field rail samples from Sterling, NE test site, areas identified by RCL meter and probe and sent by Scott Gage, AAR.

**Sterling #1, #2, #3, #4.**

Field rail samples from Buford, Georgia. Sent by Scott Gage, AAR.

**Buford #5, #6, #7, #8, #9.**

Field rail samples sent by Scott Gage, from near a crossing, Santa Fe RR.

**Sample A1, A2, A3, A4**

## **EXPERIMENTAL PROCEDURE**

### **OGI Resistance Measurements**

Using high resolution d.c. multimeter (7 digit) with simple probe. Later modified a rail profile gage to hold a test lead (insulated from profile gage). The profile gage made it possible to advance the probe across the rail head in repeatable increments. The probe itself was a polished brass tip with a radius of about 0.05 inches. A 100 gram load was applied to the probe during measurement. The probe was lifted from the rail surface between measurements. It was found that sliding the probe on the surface between measurements left a layer of brass on the surface which affected the resistance measurement. Repeat traverses were made to yield an average resistance. A ground lead was attached to the rail web, about 6 to 12 inches away from the measurement area. The measurement area was carefully cleaned with ethanol and dried thoroughly before resistance measurements were made. Resistance was measured with respect location on the rail head and plotted respectively.

### **Scrapings from Rail**

Initial exploratory work was performed on rails from Sterling Site H and Buford Site A. Samples were taken by sectioning the rail to obtain a small specimen with the film on it. Because of the impossibility of doing this in the field, a method for scraping a film sample from the rail head was developed. Basically a clean, sharp razor blade is used to scrap the rail head at a very low angle. The material scraped off tends to collect on the razor blade and rail or wheel surface. Some of this was collected on a sticky carbon dot for SEM/EDS analysis. Samples and the razor blade were then stored in clean plastic vials.

### **SEM/EDS work**

The scrapings on the sticky carbon dots were sputtered with a few angstroms of Au-Pd to produce a conductive surface on the debris, to minimize specimen charging problems in the SEM. Samples were examined in the SEM at a 10 kv accelerating voltage. A Link EDS (energy dispersive x-ray) system was used to collect x-ray spectra produced due to beam interactions between the sample and

electron beam. Analysis was at a constant beam voltage and beam diameter was adjusted to maintain count rate between samples. Due to the time involved to standardize the detector and peak analysis software for the sample configuration and the number of samples to examine; the EDS data was acquired and then a simple peak measurement/normalization done. Correction for atomic number, atomic weight, and fluorescence (ZAF) were not made to the data. Some samples will be analyzed with such corrections at a latter date. At least three diverse areas on each sample were examined to help account for possible chemical inhomogeneity.

### **TEM/Electron diffraction work**

Since the samples were in the form of a very fine dust, the probability was high that particles thin enough for electron penetration in the transmission electron microscope could be found. Dust/debris which remained on the razor blade were placed on copper grid coated with a continuous carbon film and placed directly into the TEM. The small beam size of the TEM (300 Å) enabled composition measurements in extremely small areas of each particle. Composition variations were also mapped for some of the particles. Micro-diffraction of the electron beam was used in crystalline areas for analysis of structure, covering an area of about 1000 Å. Once the diffraction patterns were indexed, the indexed results were compared to a electron diffraction pattern database for identification of the phases or phases present.

## **RESULTS**

### **SEM/EDS Analysis**

The SEM/EDS results are shown in the accompanying table. It is assumed, and there is little evidence to doubt the assumption, that the elements listed in the table are in the form of oxides. Though the amount of oxygen appears minimal in the table, in actuality once all the corrections have been applied to the data, it is actually a substantial amount. Thus, 'free' iron or aluminum was not observed. Backscattered imaging of the samples, which images based on elemental composition, showed that the scraped material was fairly uniform, at least at magnifications of 1000 to 2000 times. The iron is most likely present in the form of an iron oxide,  $\text{Fe}_2\text{O}_3$  or  $\text{Fe}_3\text{O}_4$ . The aluminum, calcium, and silicon are combined as an oxide, silicate, or a glass in the films. Silica and alumina, in either crystalline or glassy states possesses quite high resistance. Indeed, if the samples were not coated with a conductive layer (such as the gold-palladium) the imaging of the sample in the SEM would be almost impossible due to specimen charging. Electrons from the

electron beam need a conductive layer/surface/bulk to be able to flow to ground, otherwise they build or "charge".

Several groups of samples are worth noting. A brake block and wheel were obtained from AAR. The brake had been run against a machined wheel surface while the wheel ran at a constant speed and load. The film on the wheel, the brake block surface, and unaffected material from the brake block bulk, were all examined. The film on the wheel showed a high amount of silicon, some aluminum, some calcium, and some iron, and little carbon (Figure 1). The surface of the brake block showed an equivalent composition with less iron and more aluminum. The brake bulk though, showed little iron and a very high amount of carbon. It is surmised that the brake material is bonder with a carbon based binder, which consequently shows in the EDS spectra. The surface of the brake block has essentially been baked, and much of the carbon compounds volatilized. The presence of the calcium in the wheel film was somewhat of a mystery though, until a closer look, and analysis, was made of the brake block material. The brake block is a composite of several materials bound together with a carbon-based binder. Among the individual materials found in this composite were pure silica particles (spectra showed only silicon and oxygen) and numerous glass fibers of a aluminum, silica, calcium glass (spectra only showed aluminum, silicon, calcium, and oxygen). Thus it is highly likely that the calcium, silicon, and aluminum observed in the wheel film came from the brake block surface. An increased iron content of the wheel film is probably iron oxide ( $\text{Fe}_3\text{O}_4$ ) formed by oxidation of the wear debris from the wheel.

The EDS composition of the Washougal rail samples is shown in Figure 2. At this site a film was observed covering a large portion of the rail head and was notable greasy at field side of the running surface, corresponding to sample #1. Sample #3 consisted of film scrapings in the middle of contact band on the rail head. The results show a decrease in the amount of carbon, presumably oils and other hydrocarbons, as the main contact band between wheel and rail is approached. The silicon content is the highest in the contact band as well. This suggests that the processes forming and maintain the film in the contact band between wheel and rail act to exclude or minimize carbon compounds. In initial work on the Buford Site A sample received from TTC, Fast Fourier Infrared Spectroscopy (FTIR) results on rail sample with a detectable film showed no signs of hydrocarbons.

Figure 3 shows the results of analysis of rail samples taken at the Gothenburg, Nebraska site. At this site there were two sets of tracks. The south set carried east bound traffic, primarily loaded coal trains while the north track set carried mainly general freight. The north bound sample showed much more iron in the film, as iron oxide presumably, than samples from the south track set. The south track set also showed more calcium in the film. A source of calcium is the glass fibers in the composition brake shoes typically used. As the east bound trains are approaching crossing in a town, it is likely they are applying some brakes at this point. The westbound trains on the north track set are leaving the town and are not likely applying any brakes.

Rail samples taken from the Sterling, Nebraska site H are shown in Figure 4. The Site H sample, obtained from TTC early in the program shows higher carbon and iron levels than samples taken several months later. While this difference may be due to seasonal effects, some of the variation may be explained by the fact that a rail section was obtained as the initial Site H sample. Through handling, shipping, and simple normal oxidation processes, the nature of the film may have changed. With exception of the initial Buford Site A sample and the initial Sterling Site H sample obtained from TTC, all rail film samples and most wheel film samples were taken from rails and wheels fresh from use.

The Buford film rail samples, shown in Figure 5, show the same pattern and the Sterling samples, with higher iron contents in the early film samples (as iron oxide) and high silicon in later samples.

EDS composition of all rail film samples are shown in Figure 6. It can be seen that generally the film has a high silicon and iron content with some aluminum and calcium as well. Carbon was seen at times as well. The silicon, aluminum, and calcium are believed to be present in the form of a glassy oxide (confirmed by TEM work) while the iron is present as an iron oxide. All these compounds are highly resistive.

The results of 10 wheel film samples are shown in Figure 7. The amounts of iron detected are about half of that observed in rail film samples, however the silicon contents are much high. Additionally substantial amount of aluminum and calcium are present. As these elements are present in the glass fibers of composition brake shoes, it is likely that the wheel films are originating from the

braking action. Indeed the film formed on the wheel which only saw braking action (from the AAR Brake Test) is essentially the same composition as films obtain on wheels in revenue service.

### TEM/EDS Analysis

Samples for transmission electron microscopy (TEM) were made of film scrapings from the Washougal site, samples 2 and 3; the brake test wheel; the revenue wheel obtained from AAR; the Gothenburg site, south track; the sterling site, sample 3; and the Buford site, sample 8. These are still being examined, however the results thus far reveal the film to be a mixed structure of very small (10-150 Å) crystalline grains in an amorphous glassy matrix. EDS spectra taken in the TEM revealed elemental distributions to have the iron concentrated in the crystalline areas while the amorphous glassy regions, essentially a matrix, were predominantly silicon containing aluminum and calcium. While the EDS detector on the TEM is a windowed detector, incapable of detecting x-rays from light elements, analysis of diffraction patterns from the film fragments were used to get more positive identification of the phases present. Diffraction patterns from the larger crystalline regions were identified to be either  $\text{Fe}_2\text{O}_3$  and  $\text{Fe}_3\text{O}_4$ , iron oxides, or iron silicate compounds ( $\text{Fe}_2\text{SiO}_4$ ). Feldspar,  $\text{Fe}(\text{Al})\text{SiO}_4$ , was also identified in the Buford samples. Most of the crystalline regions were iron oxide. The glassy areas did not produced clearly identifiable diffraction patterns, but the observations were consistent with glassy oxide materials.

At this point the there are two probable hypothesis for the film formation. One is that under the pressures and traction forces in the wheel-rail contact zone, materials such as brake block debris and dusts from the roadbed are physically melted and mixed. The other is that under the repeat contact cycles between wheel and rail, the brake debris and trackside dusts are mechanically agglomerated into particles which are continuously broken done and re-agglomerated.

TABLE OF EDS RESULTS

Sample I.D.	% C	% O	% Al	% Si	% Ca	% Fe
Buford Site A, Rail	1.4	7.9	2.1	32.0	1.9	54.7
Buford #5, Rail	0.7	7.4	0.9	45.4	0.7	45.0
Buford #8, Rail	0.8	5.1	1.4	50.8	1.8	40.1
Sterling Site H, Rail	13.8	2.2	1.7	9.4	6.6	66.3
Sterling #1, Rail	1.8	9.4	1.7	32.0	4.5	50.6
Sterling #3, Rail	1.6	5.6	2.3	32.6	2.5	55.4
WA5-1 Rail	71.0	4.8	1.7	22.5	0	0
WA5-2 Rail	16.8	3.9	3.4	49.1	0	26.8
Sample A1	0.4	4.3	1.8	47.9	4.5	41.2
Sample A4	0.4	3.8	0.2	73.9	1.7	20.0
WA5-3 Rail	14.9	6.1	4.0	54.0	3.1	18.0
UP Wheel, UP 218228	13.3	10.7	5.8	61.2	1.4	7.6
BN Wheel, BN 624136	19.7	11.1	10.7	46.0	2.9	9.6
AAR Brake Wheel	14.5	9.3	3.8	55.2	1.4	15.9
AAR Brake block, surf.	11.3	4.3	36.7	43.5	0	4.2
AAR Brake block, bulk	56.2	2.0	15.2	24.0	0	2.7
AAR Car Wheel	14.7	15.0	9.0	42.4	3.0	16.0
NORX 2488 L3	2.2	2.9	17.0	63.8	6.2	8.0
NORX 2488 R3	0.9	6.7	8.3	65.0	2.9	16.1
UP 79760 Wheel	2.1	5.8	10.1	64.4	6.2	7.9
North Rail, Gothenburg	14.1	5.1	5.1	39.1	18.6	17.9
South Rail, Gothenburg	11.5	14.3	1.9	32.5	1.3	39.0
KCLX 91054 L1	0.4	3.8	6.6	58.6	16.3	14.3
Wheel 57990	0.3	7.1	6.2	53.0	4.6	28.9
Wheel 47166	1.8	5.1	10.7	57.4	2.3	22.7

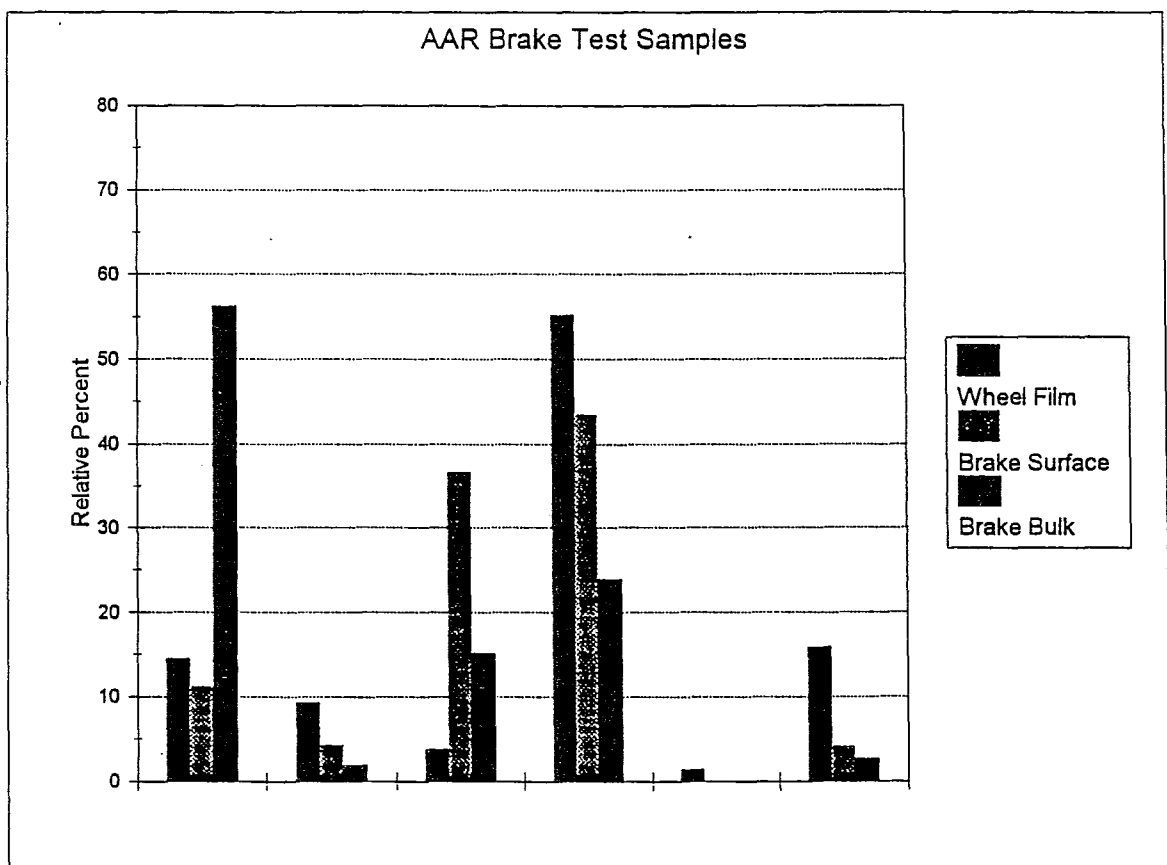


Figure 1. EDS Spectra of AAR Brake Test Samples

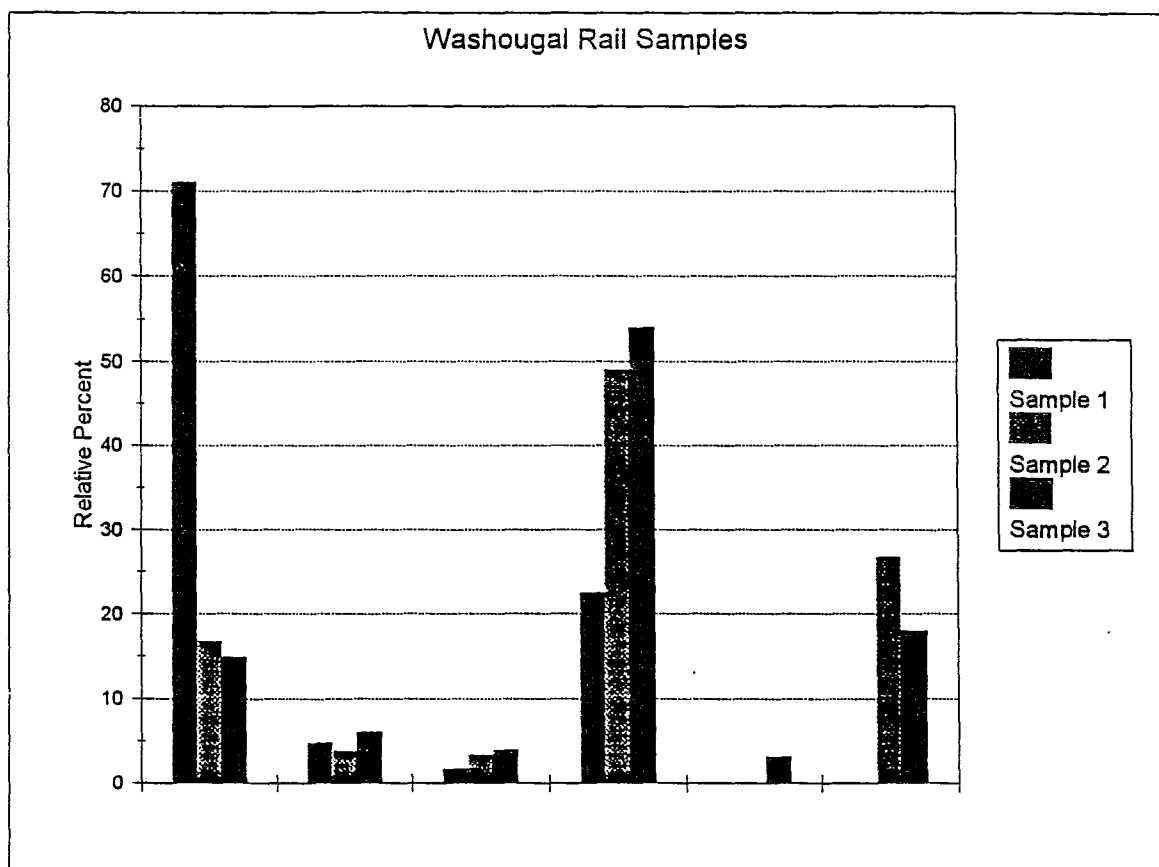


Figure 2. EDS Spectra of Washougal Rail Samples

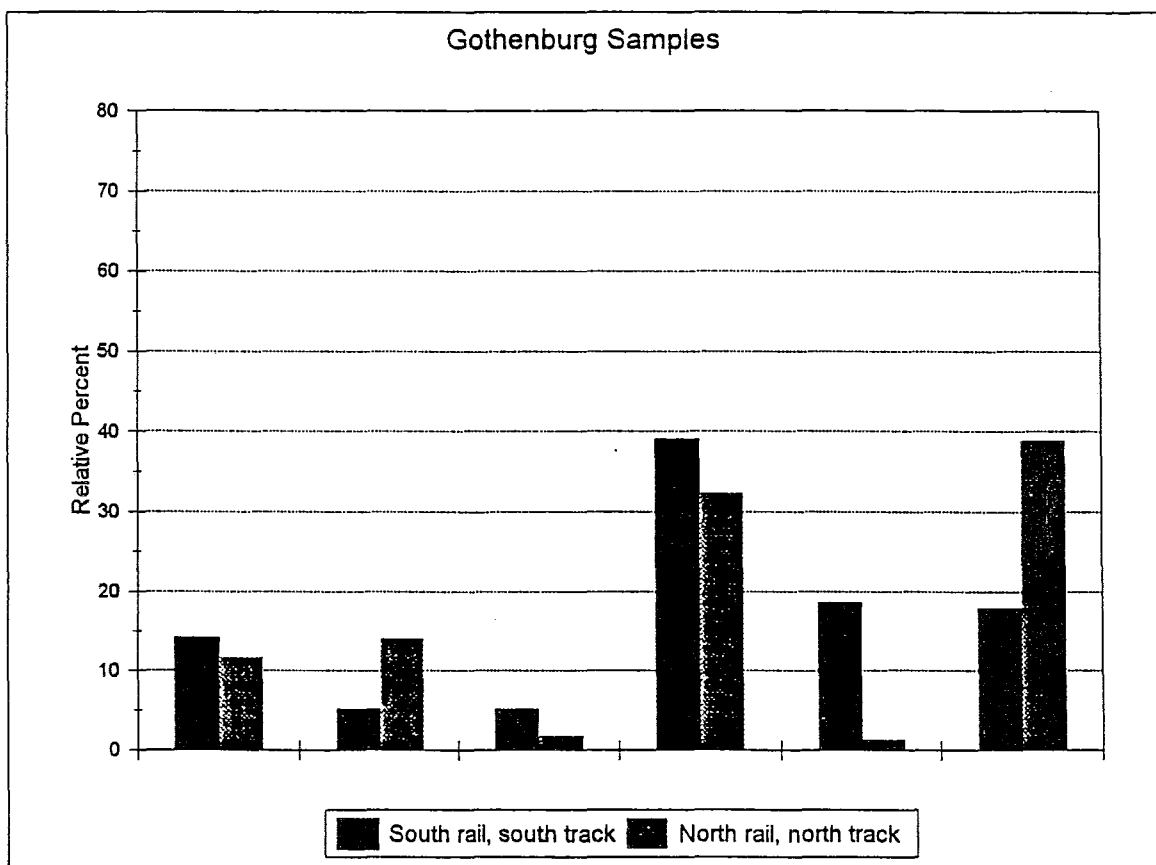


Figure 3. EDS Spectra of Gothenburg Rail Samples

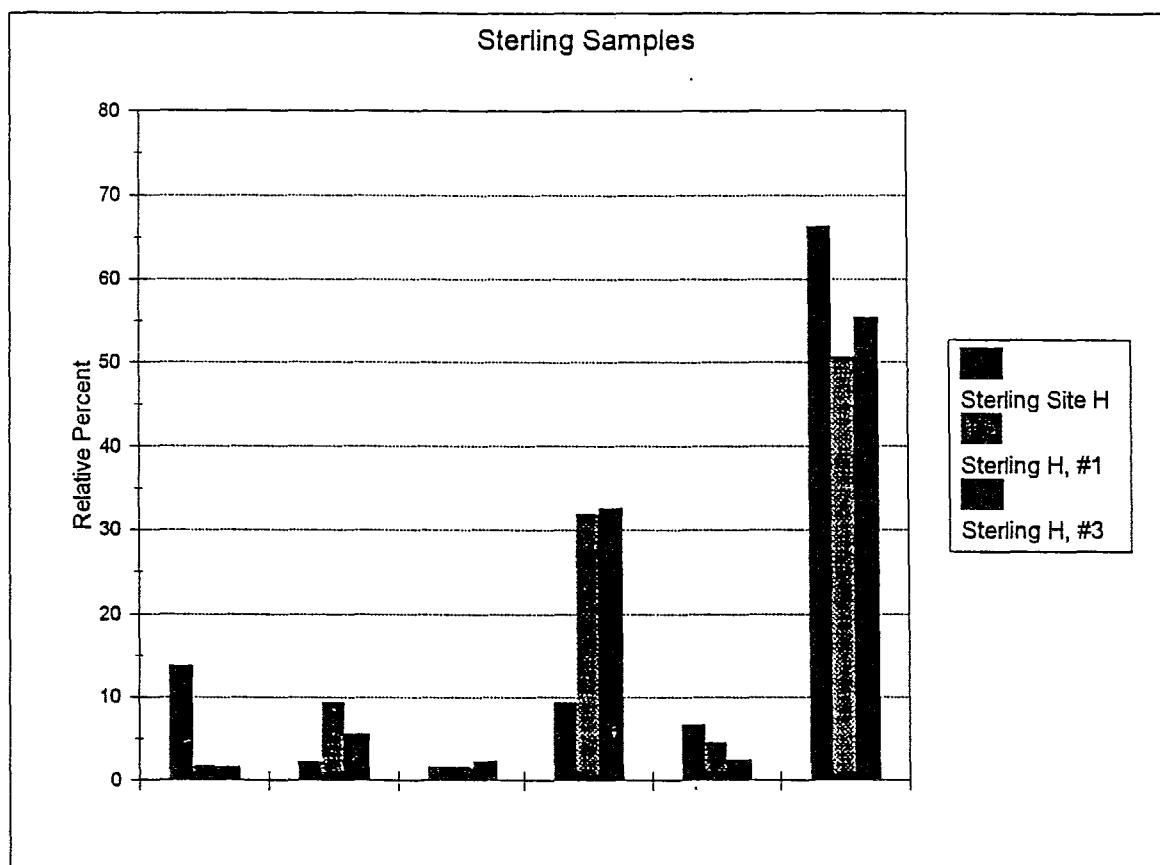


Figure 4. EDS Spectra of Sterling Rail Samples

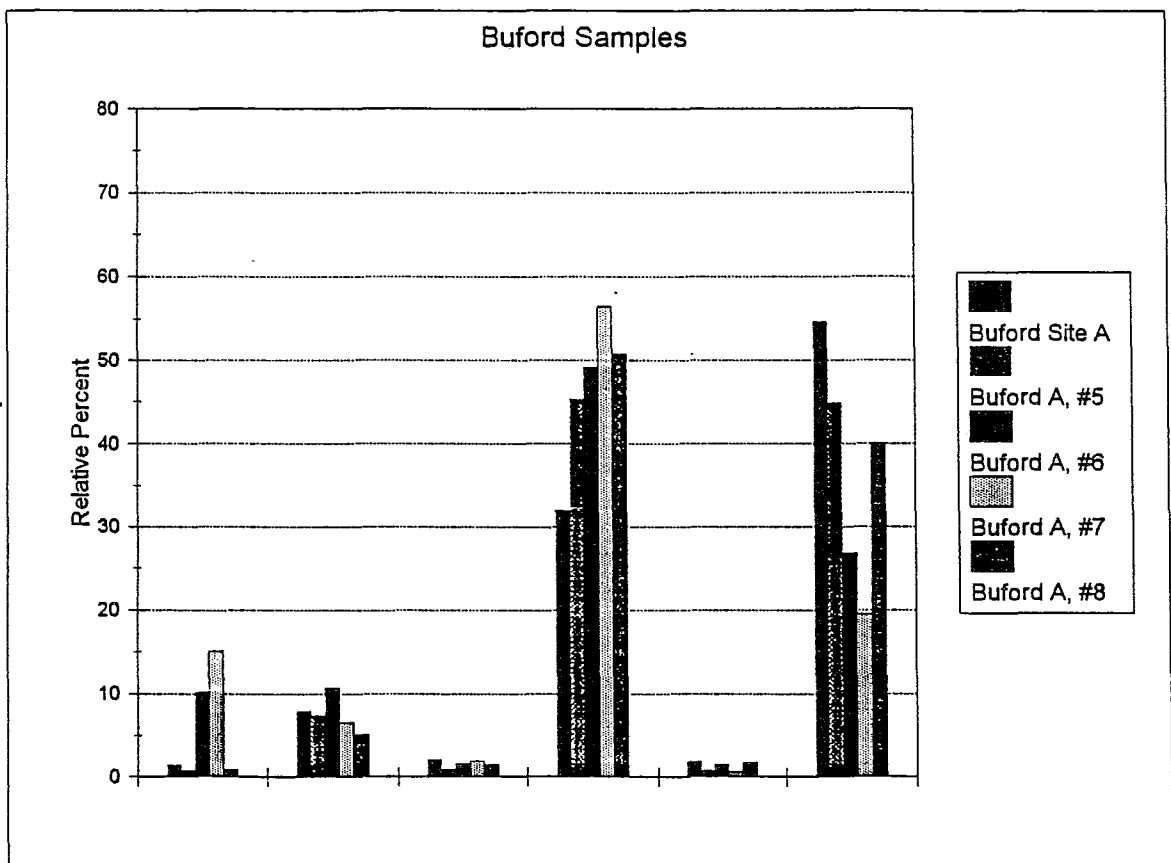


Figure 5. EDS Spectra of Buford Rail Samples

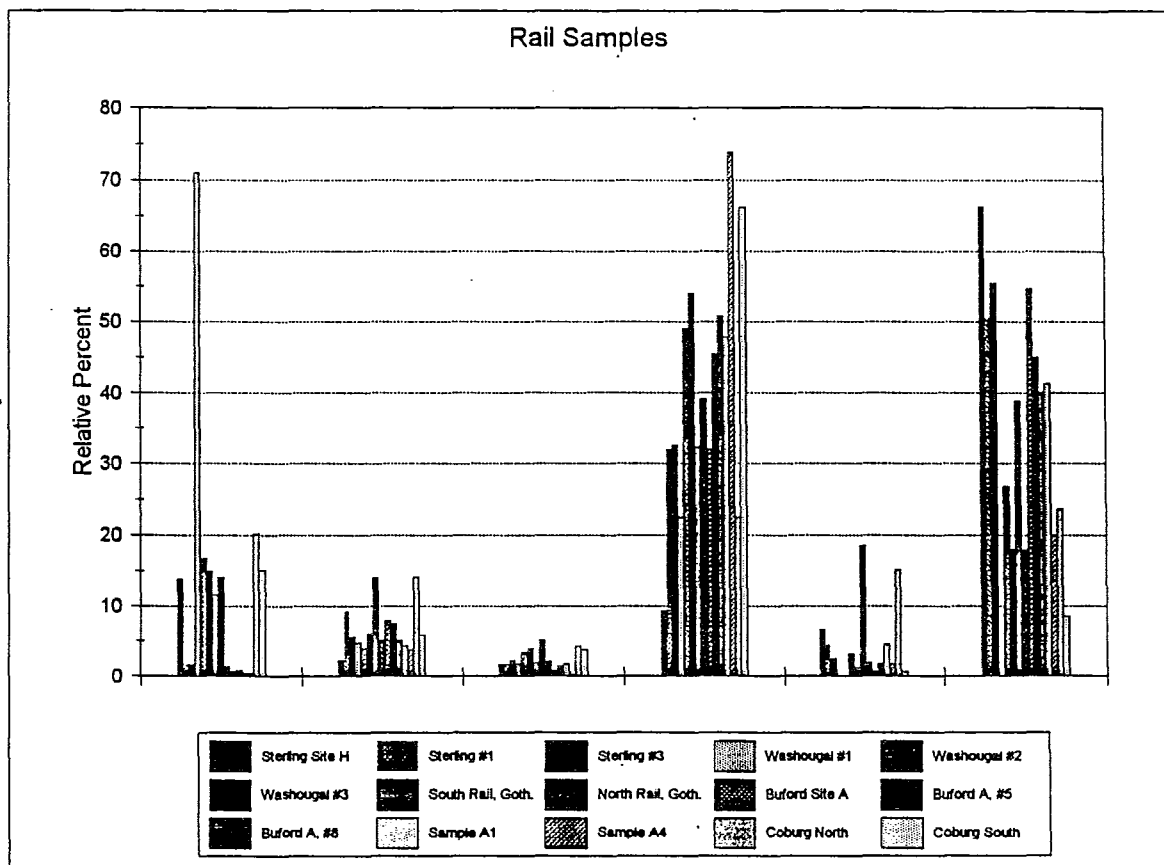


Figure 6. EDS Spectra of All Rail Samples

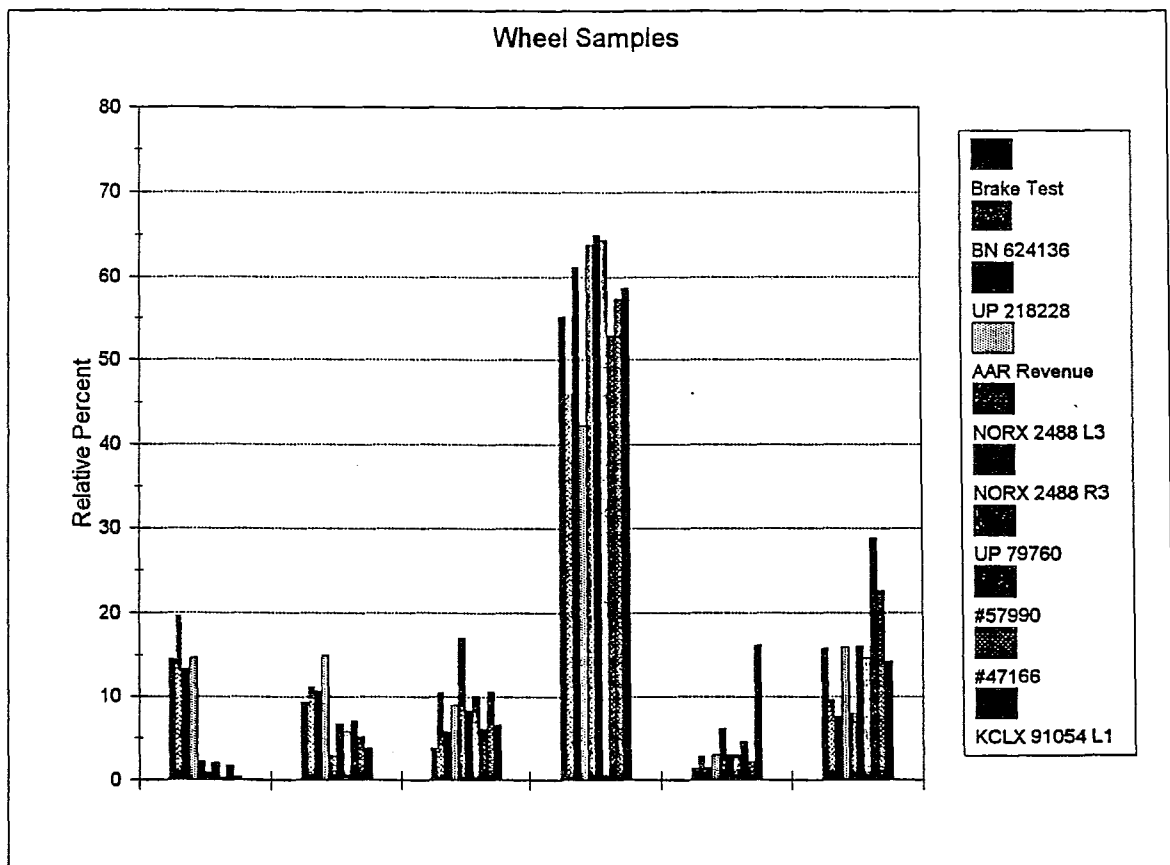


Figure 7. EDS Spectra of All Wheel Samples

## **APPENDIX C**

### **Dynamometer Test Run Log**

## *Test Sequence A*

### OBTAINED FILM SAMPLES A, B

- Run 000a - Heavily contaminated track wheel, rust and residue present from over a years period of no operation of track wheel.
- Run 001a, 002a - No data, system check out.
- Run 003a - Re-run heavily contaminated case

### FILM SAMPLES C, D CLEANED BOTH WHEELS

- Run 004a - Clean wheel on clean wheel, no brake application, 6300 lbs wheel load, 5 mph
- Run 005a - Clean wheel on clean wheel, no brake application, 6300 lbs wheel load, 20 mph
- Run 006a - Repeat run 005, increased to 40 mph on the fly.
- Run 007a - Decreased to 5 mph from 40 mph of previous run.

### FILM SAMPLE E

- Run 008a - Clean wheel on clean wheel, no brake application, 32000 lbs wheel load, 5 mph
- Run 009a - Continue run 008, increased to 20 mph
- Run 010a - Repeat run 009, increased to 40 mph on the fly. Coast to a stop @210 seconds
- Run 011a - Light brake application (925 lbs.), increased brake application to 1450 lbs. @ 1450 seconds.

### FILM SAMPLES F & G

- Run 012a - Brake malfunction, no data
- Run 013a - Obtained speed of 40 mph, applied brake and released when speed declined to 5 mph. Repeated for 3 cycles.
- Run 014a - Added lubrication, allowed water to drip on track during running, shut water off and proceeded with 3 cycle braking accelerating to 40 mph each time. Wheel load at

6,300 lbs.

- Run 015a - Added lubrication while rotating at slow rpm. Accelerate to 40 mph.

FILM SAMPLES H & I

- Run 016a - Increased wheel load to 32,000 lbs. Added lubrication at slow rpm and then accelerated to 40 mph. Higher wheel load squeezed lube out of the running surface as it was being applied.

FILM SAMPLES J & K

- Run 017a - Added lubrication at slow rpm, Increased speed to 40 mph, no braking, wheel load at 12,000 lbs. - stopped data collection @ 450 sec.
- Run 018a - Increased wheel load to 18,000 lbs., added lube at slow rpm, increased speed to 40 mph, decelerate at 320 sec.
- Run 019a - Increased wheel load to 24,000 lbs., re-applied lubrication at slow rpm, increased to 40 mph.
- Run 020a - Reduced wheel load to 9,000 lbs, repeated run 019a sequence.
- Run 021a - Reduced wheel load to 6,300 lbs, added lube at slow rpm, accelerated to 40 mph. Re-applied lube during the run @ 500 sec at 40 mph.
- Run 022a - Increased wheel load to 12,000 lbs, accelerate to 40 mph, added lube @ 140 sec at 40 mph.
- Run 023a - Hand wiped the excess lube from the track wheel surface. Began brake application. Accelerated to 40 mph, used 3,300 lbs brake force and released brake when the speed was 5 mph, this cycle was repeated three times. Run terminated @ 540 sec.
- Run 024a - Continued with run 023a. Added additional lube after first braking cycle.
- Run 025a - Wiped track wheel and car wheel with cloth rags to remove excess lubrication. Repeated the run 024a.

REMOVED BRAKE SHOE FOR PHOTO/FILM SAMPLE FROM SHOE SURFACE

- Run 026a - Repeated run 025, performed four braking cycles.
- Run 027a - Increased wheel load to 18,000 lbs, repeated run 026a, three cycles

FILM SAMPLE M

- Run 028a - Reduced wheel load to 9,000 lbs, repeated previous run sequence
- Run 029a - Reduced wheel load to 6,300 lbs, accelerated to 40 mph, one brake application then stopped.
- Run 030a - Added lubrication to the car wheel of approx 18 inches to introduce a small presence of lube in an effort to repeat earlier results. Repeated three cycle braking application from 5 to 40 mph.
- Run 031a - Computer general protection fault error - No Data
- Run 032a - Added lubrication to the track wheel, ran at 40 mph for 200 seconds, sand was added @ 55 sec. Continued with three cycle braking.

#### FILM SAMPLE N

- Run 033a - Repeated run 032a, used dirt instead of sand. Continued with 3 cycle braking

#### FILM SAMPLE O

- Run 034a - Hand wiped both wheels, repeated parameters of 032a & 033a introduced leaves, organic mixture.
- Run 035a - Varied voltage; @ 320 sec - 2 volts; @ 400 sec - 1.5 volts; @ 690 sec - 1.2 volts; @ 750 sec - 1.0 volt; @ 810 sec - 0.8 volts; @ 900 sec - 0.5 volts; @ 1200 sec - 10 volts.
- Run 036a - Applied lubrication, ran at 40 mph with water running continuously. Cyclic braking activity
- Run 037a - No Data
- Run 038a - Repeated run 036a, brake force increased to 6,050 lbs.

### ***Test Sequence B***

#### FILM SAMPLE 2A

- Run 003b - Apply lubrication at slow rpm, accelerated to 40 mph, reduced speed using regenerative braking.
- Run 004b - Hand wiped excess lube, acyl. to 40 mph, regenerative braking
- Run 005b - No Data

- Run 006b - Re-applied lubrication, repeat run 004b.
- Run 007b - Hand wiped excess lube, repeat run 006b.
- Run 008b - Re-applied lube, accelerated from to 40 mph for three cycles. Used regenerative braking to slow the dyno.
- Run 009b - Re-applied lube, accelerate to 40 mph, cycled from 5 to 40 mph four times using a 3,290 lbs brake application.

#### FILM SAMPLE 2B

- Run 010b - Applied mixture of locomotive sand and lubrication at slow rpm, cycled three times, first cycle used regenerative braking, the following used brake application.
- Run 011b - Reduced speed to 20 mph from previous run, drag brake shoe application at 1,500 lbs

#### FILM SAMPLE 2C

- Run 012b - Added dirt to previous mixture of lube and sand, applied mixture, repeated run 010b.
- Run 013b - Added grass clippings and leaves to mixture and applied, Ran two cycles at 40 mph, no brakes were applied.

#### FILM SAMPLE 2D, 2E CLEANED BOTH WHEEL WITH ACETONE

- Run 014b - No Data
- Run 015b - Ground a groove in the brake shoe to simulate a non-conformal contact in line with the running surface. Repeated three cycle brake run from 5 to 40 mph.
- Run 016b - No Data
- Run 017b - Added lube at slow rpm, repeated run 015b
- Run 018b - No Data
- Run 019b - Re-applied lubrication, repeat cyclic braking activity with one cycle of regenerative braking.

### *Test Sequence C*

- Run 011c, 012c - No data, check out runs.
- Run 013c - Brake application only. Accelerated to 40 mph, 3,290 lbs brake appl., acyl to 40 mph, brake and released at 20 mph twice, then coast
- Run 014c - Added lubrication, accelerate to 40 mph, sustain and regenerative braking
- Run 015c - Re-applied lube, repeat run 014c.
- Run 016c - Redistributed existing lubrication, ran 3 cycles using regenerative braking.
- Run 017c - Redistributed existing lube, ran at 40 mph, 3,290 lbs braking applied at 420 seconds into the run for three cycles releasing at 20 mph
- Run 018c - Added mixture of lube, sand, dirt, and organic material from test series B, accelerated to 40 mph, maintained, no braking
- Run 019c - Redistributed lube mixture, accelerated to 40 mph, used regenerative braking to cycle from 40 to 20 mph.

#### FILM SAMPLE 3A, 3B CLEANED WHEELS WITH DIESEL FUEL

- Run 020c - Accelerate to 40 mph
- Run 021c - No Data - Brake malfunction
- Run 022c - Light drag brake application (925 lbs) at 20 mph.
- Run 023c - Ran at 40 mph to check effects of previous drag brake application. Used regenerative braking to cycle.
- Run 024c - Light brake appl. to stop previous run.
- Run 025c - Applied lube mixture, used light brake application of 925 lbs to cycle from 40 to 20 mph.
- Run 026c - Added additional mixture, repeat previous run.

#### FILM SAMPLE 3C, 3D

- Run 027c - Redistributed mixture, light (925 lbs) and heavy (3,290 lbs) brake application

FILM SAMPLE 3E, 3F